

## **Internal Waves in Straits Experiment Progress Report**

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### **LONG-TERM GOALS**

Our long-term goal is to understand how energy is supplied to the ocean, and how it subsequently cascades to the turbulence and mixing important to the circulation, and the transport and distribution of tracers. This problem involves scales spanning sub-inertial motions to turbulence, and therefore requires integrative efforts with other sea-going investigators and numerical modelers. The South China Sea project was an ideal opportunity to investigate the cascade from internal tides to higher frequency waves through the processes of internal wave scattering and non-linear steepening.

### **OBJECTIVES**

To understand the modification of internal tides as they encounter the continental shelf.  
To understand how energy partitions between linear and non-linear internal waves in the internal tide generation region of the South China Sea  
To determine sites of high turbulence dissipation at the generation site.

### **APPROACH**

To date, my approach for this project has been to use a numerical modeling to understand where turbulence dissipation will occur over supercritical topography. These numerical models are two-dimensional iterations of the MITgcm, so relatively high resolution runs are attainable as are many iterations allowing the examination of significant parameter space.

I have also strongly believe that numerical modeling must be informed by at-sea measurements, and vice-versa. To that end I have worked with Rob Pinkel and the rest of the IWISE pilot team to help plan the pilot experiment, and participated on Pinkel's leg in June 2010.

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## WORK COMPLETED

Preliminary numerical model runs were made in two-dimensions that had idealized tidal forcing over realistic SCS topography. A set of runs with very idealized 3-d forcing was run to examine the interactions of two source sills in producing non-linearities. Finally, I participated in the June 2010 Pilot field program with Rob Pinkel's group from SIO, where I led the at-sea data analysis and partnered with Rob for the at-sea planning.

## RESULTS

I worked with Alford and co-workers to try and understand the timing and evolution of solitary waves as they cross the deep basin. This has led to a number of simple numerical model runs not dissimilar to the work by Buijsmans et al. While this work may not lead directly to a publication, it has helped with Alford et al. (2010).

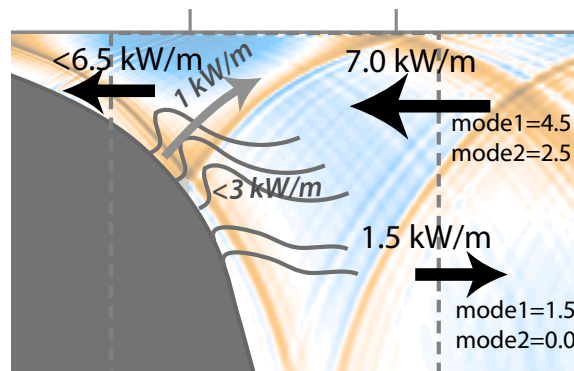
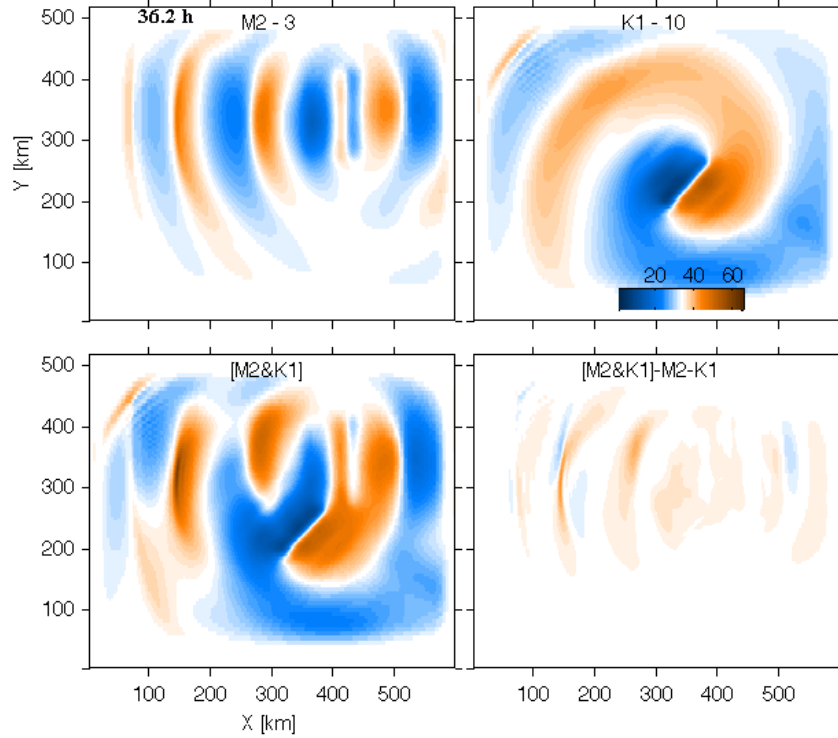


FIG. 27. Sketch of rough diurnal ( $D_1$ ) energy budget inferred from the observations. Local generation from a linear model and the upper bound on the dissipation as extrapolated from MP1 are noted in gray, as they are not very well constrained. The shoreward estimate at MP1 is also an upper bound and only from modes 1 and 2.

This program has also partially funded analysis on SCS07 data set looking at reflections from the continental slope (figure 1). Here we found a fascinating interplay between incoming and reflected internal tides, whereby mode-1 energy backreflects as mode-2 energy, setting up an interference pattern with incoming mode-2 energy (Klymak et al., 2011). This highlights the difficulty with just looking at net energy budgets to interpret internal wave generation and reflection.

A discussion that took place as part of the pilot planning was whether two independent sources of internal wave energy could couple non-linearly to produce internal solitons in the middle of the basin. To help answer the question, I spun up some idealized 3-D models that isolated idealized tides from the rest of the forcing problem. These showed that indeed the tides, when of sufficient amplitude, could couple non-linearly, even when propagating at oblique angles to one another (figure 2), confirming an effect that seemed to show up in Simmons' more complex fully realistic models, and giving the pilot experiment planners more confidence about the importance of checking the physics at the southern ridge.

My major focus has been investigating the dissipation local to the generation site. As outlined in Legg and Klymak (2008); Klymak et al. (2010a) there are high-mode hydraulic jumps found at the flanks of

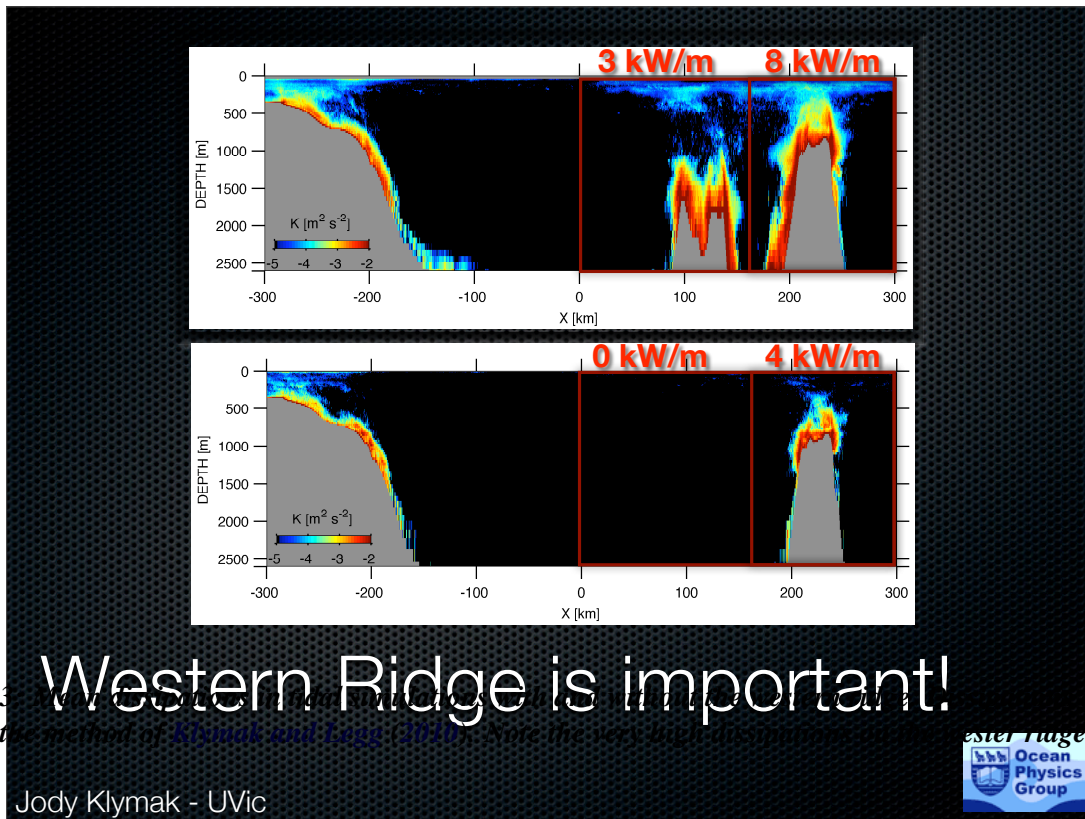


**Figure 2: Three dimensional simulations, with just an M2 source, just a K1 source, and their combination, and the non-linear coupling. In the last frame, we can see the non-linear front at X=150 has been formed by coupling between the two tidal components.**

supercritical topography that contain most of the turbulence in the system. The experiment at Luzon Strait will be a particularly interesting test of this phenomena because the forcing there is very strong compared to at Hawaii. I have been running numerical runs that more closely match the Luzon system to see how large the breaking lee waves might be.

This extreme environment will be a good test bed for the ideas I have been developing about parameterizing the dissipation due to internal tides over supercritical topography (Klymak et al., 2010b). This method uses the linear generation of internal tides to predict how much energy is available to go into these arrested lee waves, and is therefore relatively simple and amenable for inclusion in numerical models. Whether these simple models are borne out in the more extreme environment afforded by Luzon Strait, both numerically and in the observations remains to be tested.

Luzon is also fascinating because it has a double ridge, and the ridges are almost exactly an M2 mode-1 wavelength apart, allowing for resonances to set up between the ridges. Preliminary 2-D modelling (figure 3) shows that there are large near-ridge dissipations at all depths. This seems likely to be caused by more than just the hydraulic processes we have attempted to parameterize in Klymak et al. (2010b), with significant turbulence on the flanks of the topography. Also, with the same forcing, we see considerably more turbulence in the simulation with a western ridge, implying that interesting physics are going on between the ridges.



Finally, I took to sea with Rob Pinkel's group to help test some of these ideas as part of the IWISE pilot. We occupied 7 stations in Luzon Strait at 20.56 N to examine the variability of the tidally forced motions and turbulence using Lowered ADCPs. We found strong internal tidal fluxes, though often in somewhat confusing directions, indicative perhaps of strong influence of standing patterns set up between the ridges. All the stations showed very high dissipation rates, often reaching three-orders of magnitude open ocean values (figure 4), and easily matching near-bottom turbulence seen at Hawaii. Dissipation is phase locked with the tide, like at other steep ridges.

## IMPACT/APPLICATIONS

We think we have identified an important mechanism for scattering and dissipating low-mode internal tides. This set of observations and the accompanying modeling should help in our ultimate goal of making simple models of these processes in the ocean.

## RELATED PROJECTS

This work is strongly tied to the work by PIs Pinkel, Lien, Simmons, and Alford. I am collaborating extensively with them in data analysis and modeling.

It is related to the work being done in the AESOP DRI, which also seeks to understand the mechanisms that break low-mode energy down into high-mode unstable waves.

Finally, it is complimentary to Klymak's work at UVic, funded through the Canadian National Science and Engineering Research Council, to look at coastal internal wave processes.

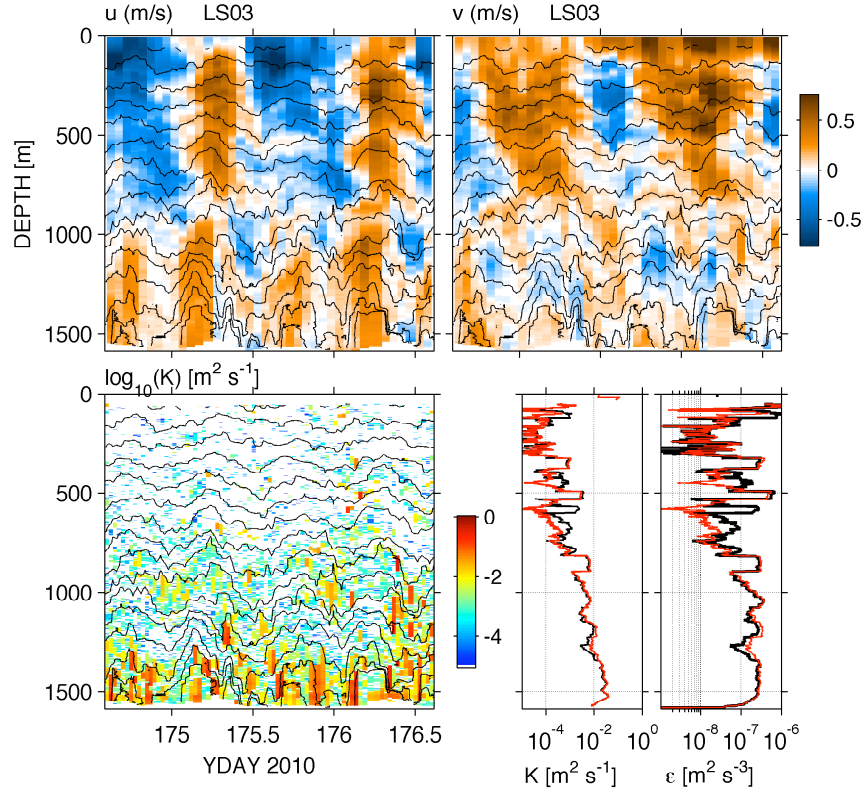


Figure 6.

**Figure 4: Velocities, isopycnal, and overturn-based turbulence estimates from the west flank of Luzon Strait. Note the very high turbulence dissipation rates near the seafloor phase locked with the tide.**

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